Physics 141, Midterm Exam #3

Thursday December 12, 2006

8.00 am – 9.30 am

Do not turn the pages of the exam until you are instructed to do so.

You are responsible for reading the following rules carefully before beginning.

Exam rules: You may use *only* a writing instrument and your equation sheet while taking this test. You may *not* consult any calculators, computers, books, nor each other.

Answer the multiple-choice questions (problems 1 – 10) by marking your answer on the scantron form. For each multiple-choice question (problems 1 – 10), select only one answer. Questions with more than one answer selected will be considered incorrect. Problems 11, 12, and 13 must be answered in the blue exam booklets **(answer questions 11 and 12 in booklet 1 and question 13 in booklet 2.)** The answers need to be well motivated and expressed in terms of the variables used in the problem. You will receive partial credit where appropriate, but only when we can read your solution. Answers that are not motivated will not receive any credit, even if correct.

At the end of the exam, you need to hand in your exam, the blue exam booklets, and the scantron form. All items must be clearly labeled with your name and student ID number. If any of these items are missing, we will not grade your exam, and you will receive a score of 0 points.

NOTE: If your student ID is not listed properly on the Scantron form, the form will not be processed and you loose points for all multiple-choice questions.

Name: ____

ID number: ____

Recitation Day/Time: ___________________________________

Useful Relations:

$$\cos(30°) = \frac{1}{2}\sqrt{3} \quad \sin(30°) = \frac{1}{2} \quad \tan(30°) = \frac{1}{3}\sqrt{3}$$

$$\cos(45°) = \frac{1}{2}\sqrt{2} \quad \sin(45°) = \frac{1}{2}\sqrt{2} \quad \tan(45°) = 1$$

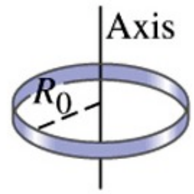
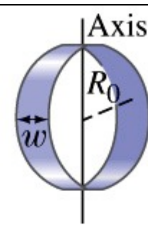
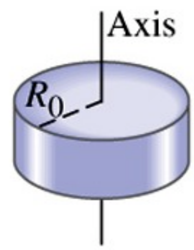
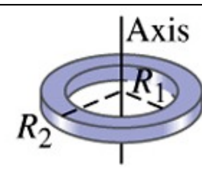
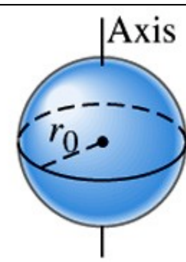
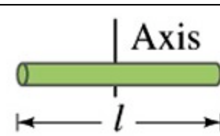
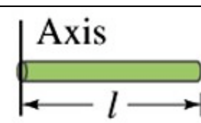
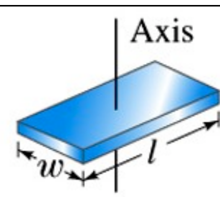
$$\cos(60°) = \frac{1}{2} \quad \sin(60°) = \frac{1}{2}\sqrt{3} \quad \tan(60°) = \sqrt{3}$$

$$\cos\left(\frac{1}{2}\pi - \theta\right) = \sin(\theta) \qquad \sin\left(\frac{1}{2}\pi - \theta\right) = \cos(\theta)$$

$$\cos(2\theta) = 1 - 2\sin^2(\theta) \qquad \sin(2\theta) = 2\sin(\theta)\cos(\theta)$$

	circle	sphere
circumference	$2\pi r$	
(surface) area	πr^2	$4\pi r^2$
volume		$\frac{4}{3}\pi r^3$

Moments of inertia of various objects of uniform composition.

(a)	Thin hoop of radius R_0	Through center		MR_0^2
(b)	Thin hoop of radius R_0 and width w	Through central diameter		$\frac{1}{2}MR_0^2 + \frac{1}{12}Mw^2$
(c)	Solid cylinder of radius R_0	Through center		$\frac{1}{2}MR_0^2$
(d)	Hollow cylinder of inner radius R_1 and outer radius R_2	Through center		$\frac{1}{2}M(R_1^2 + R_2^2)$
(e)	Uniform sphere of radius r_0	Through center		$\frac{2}{5}Mr_0^2$
(f)	Long uniform rod of length l	Through center		$\frac{1}{12}Ml^2$
(g)	Long uniform rod of length l	Through end		$\frac{1}{3}Ml^2$
(h)	Rectangular thin plate, of length l and width w	Through center		$\frac{1}{12}M(l^2 + w^2)$

Problem 1 (2.5 points)


1


2


3


4

Match the above shown players of the best baseball team in the world with the following names:

A. Derek Jeter

B. Mariano Rivera

C. Johnny Damon

D. Jorge Posada

1234 =

1. ABCD
2. ACDB
3. BADC
4. BDAC
5. CADB
6. CABD
7. DBAC
8. DCBA

Problem 2 (2.5 points)

As you hold the string, a yoyo is released from rest so that gravity pulls it down, unwinding the string. What is the angular acceleration of the yoyo, in terms of the string radius R, the moment of inertia I, and the mass M?

1. $g/(R + 2I/(MR))$
2. gMR/I
3. $gMR/(I + MR^2)$
4. g/R

Problem 3 (2.5 points)

Suppose you are holding a bicycle wheel by a handle, connected to the axle, in front of you. The axle points horizontally away from you and the wheel is spinning clockwise from your perspective. You now try to tilt the axle to your left (center of mass moves leftward). The wheel will swerve

1. upward.
2. downward.
3. to your left.
4. to your right.

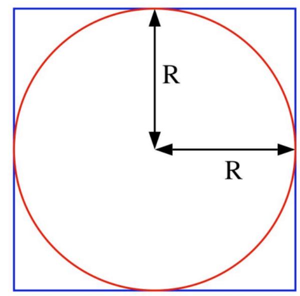
Problem 4 (2.5 points)

An ideal gas is contained in a small volume, which is connected to a much larger volume that contains a vacuum. Both volumes are insulated. When the valve between the two volumes is opened, the gas will expand until it fills both volumes. During this expansion, the gas

1. does positive work.
2. increases its internal energy.
3. decreases its internal energy.
4. does not change its internal energy.

Problem 5 (2.5 points)

The moment of inertia of a square plate of area $4R^2$ and mass M, with respect to an axis through its center and perpendicular to the plate, is equal to $(2/3)MR^2$. A disk of radius R is removed from the center of the plate (see Figure). What is the moment of inertia of the remaining material with respect to the same axis?



1. $(\pi/8)MR^2$
2. $(1/3 - \pi/12)MR^2$
3. $(1/6)MR^2$
4. $(2/3 - \pi/8)MR^2$

Problem 6 (2.5 points)

What is the heat capacity per atom or molecule in a solid

1. $3k$
2. $3/2\ k$
3. $5/2\ k$
4. $7/2\ k$

Problem 7 (2.5 points)

What is the heat capacity at constant volume of a diatomic gas at a temperature T where kT is large compared to the energy of the first vibrational excited state?

1. $3k$
2. $3/2\ k$
3. $5/2\ k$
4. $7/2\ k$

Problem 8 (2.5 points)

According to the Fundamental Assumption of Statistical Mechanics, which of the following states of an atom with three degrees of freedom and three quanta of energy is most probable?

1. One degree of freedom with 3 quanta of energy and two degrees of freedom with 0 quanta of energy each.
2. One degree of freedom with 2 quanta of energy, one degree of freedom with 1 quantum of energy, and one degree of freedom with 0 quanta of energy.
3. Three degrees of freedom with 1 quantum of energy each.
4. None of the above, because all microstates are equally probable.

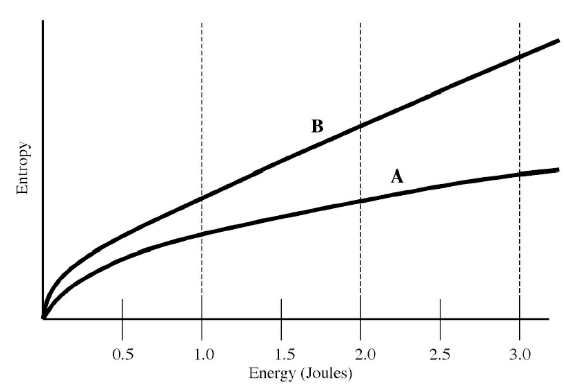
Problem 9 (2.5 points)

Two wheels, initially at rest, roll the same distance without slipping down identical inclined planes. Wheel *B* has twice the radius but the same mass as wheel *A*. All the mass is concentrated in their rims, so that the rotational inertias are $I = mR^2$. Which wheel has **the largest rotational kinetic energy** when it gets to the bottom?

1. Wheel *A*.
2. Wheel *B*.
3. The rotational kinetic energies are the same.
4. Need more information.

Problem 10 (2.5 points)

The figure on the right shows a plot of the entropy of two different metal blocks as a function of the internal (thermal) energy. Suppose the blocks (labeled *A* and *B*) are isolated from each other and are warmed until they each have 2 Joules of



thermal energy. Which block has a **lower temperature** at this energy?

1. Block *A* has a lower temperature.
2. Block *B* has a lower temperature.
3. They have the same temperature since the thermal energy is the same.
4. There is not enough information to determine the temperature. The mass and specific heat of each block must be provided.

Problem 11 (25 points) **ANSWER THIS QUESTION IN BOOKLET 1.**

A cylinder with cross sectional area A contains N molecules of helium gas at pressure p_0. The cylinder is in thermal equilibrium with a heat bath of temperature T_0. A piston confines the gas inside a region of volume V_0. The entire system is contained in a vacuum vessel, and only the helium gas exerts a pressure on the piston. Assume that $\gamma = C_p/C_V = 5/3$ (for Helium).

a. You quickly pull up the piston to increase the volume of the gas to V_f. What is the temperature T_f of the gas immediately after you finish pulling up the piston? What approximations did you make?

b. What is the work done by the gas during this expansion?

c. What is the force you must exert on the piston, immediately after you finish pulling it up, in order to hold it into its final position?

d. You wait until the helium returns back to its original temperature T_0. What is now the force you must exert on the piston in order to hold it into its final position?

e. You now very slowly move the piston back to its original position such that the gas is contained in a volume V_0. How much work must you do to move the piston back to this position? Is the magnitude of this work larger or smaller than the magnitude of the work calculated in part b? What approximations did you make?

Problem 12 (25 points) **ANSWER THIS QUESTION IN BOOKLET 1.**

a. What is the heat capacity per molecule at constant volume of a monatomic gas, such as helium or neon. Why doesn't the heat capacity depend on temperature?

b. What is the heat capacity per molecule at constant volume of a diatomic gas, such as oxygen and nitrogen, at very high temperatures?

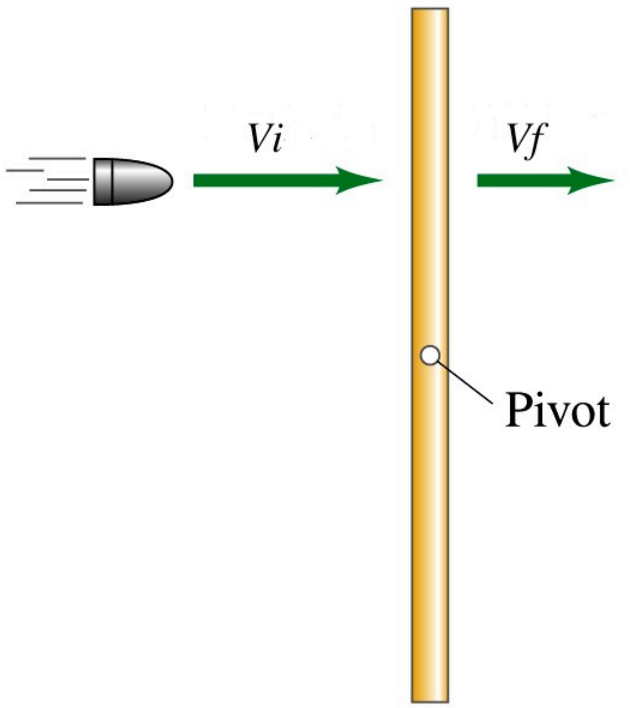
c. Suppose we lower the temperature of a diatomic gas to a point where kT is small compared to the first excited rotational state. What is the heat capacity per molecule at constant volume of this gas at this temperature?

d. The transition temperature $T_{\text{transition}}$ is the temperature at which the rotational properties of the gas molecules need to be taken into consideration when describing the properties of a gas. Consider the following two gases: H_2 (hydrogen, whose nuclei contain a single proton) and D_2 (deuterium, whose nuclei contain a proton plus a neutron). Estimate the ratio of the transition temperatures of these gases, $T_{\text{transition, hydrogen}}/T_{\text{transition, deuterium}}$. Your answer needs to be well motivated and any approximations you have made must be clearly stated.

e. Consider two volumes of hydrogen and deuterium gas, both maintained at the same temperature T. The temperature T is low enough to ensure that the rotational and vibrational states are not excited. Estimate the ratio of the speed of sound in hydrogen and deuterium gas, $v_{\text{sound, hydrogen}}/v_{\text{sound, deuterium}}$. Your answer needs to be well motivated and any approximations you have made must be clearly stated.

Problem 13 (25 points) **ANSWER THIS QUESTION IN BOOKLET 2.**

A uniform stick of length *H* and mass *M*, initially at rest, is pivoted at its center. A bullet of mass *m* is shot through the stick, midway between its pivot and one end (see Figure).



The bullet approaches the stick with a velocity v_i and leaves with a velocity $v_f = (1/2)v_i$. You can ignore the change in the mass and the moment of inertia of the rod as a result of the bullet passing through it. You can also ignore the effect of gravity.

a. What is the initial angular momentum of the bullet with respect to the pivot point? Specify both its magnitude and its direction.

b. What is the final angular momentum of the bullet with respect to the pivot point? Specify both its magnitude and its direction.

c. With what angular speed is the stick spinning after the collision?

d. How much energy is lost in the collision?

Express all your answers in terms of *m*, *M*, *H*, and v_i.